Approach for Developing an Uncertainty Range for the *Status Report on Paths to Closure* Life-cycle Cost Estimate

This attachment discusses the methodology for developing an uncertainty range for the *Status Report on Paths to Closure* life-cycle cost estimate. Cost uncertainty, or cost growth between cost estimates and actual costs is a common problem in addressing environmental projects. The EM program is particularly susceptible to cost uncertainty due to the unique nature of nuclear weapons complex cleanup efforts.

- Due to large quantities of unique contaminants and atypical mixtures of these contaminants, there is an elevated demand for innovative cleanup technologies.
- These unique materials often lead to a need for complex, multi-stage remediation processes.
- Facility-related cleanup projects involving deactivation and decommissioning include a relatively high proportion of one-of-a-kind DOE facilities.

Cost uncertainty analysis seeks to take into account those factors that may not be considered in a typical estimate and use them to generate a range reflecting uncertainties in the estimate. This discussion addresses how cost uncertainty drivers—the factors with the greatest potential to affect costs over the life of a project—have been applied to the *Status Report on Paths to Closure* life-cycle cost point estimate.

Conceptual Overview

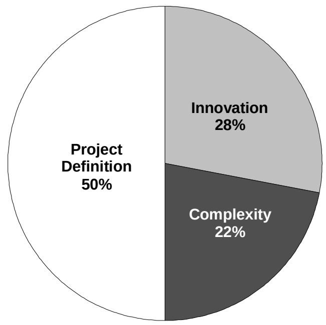
Cost uncertainty literature identifies five key cost uncertainty drivers associated with the construction of new types of process plants[1]. Three of these drivers are relevant for environmental projects: project definition, innovation, and complexity. The other two drivers discussed in the study[2] were excluded due to their lack of applicability when considering remediation projects. **Project definition**, the most significant of the three drivers, represents the level of site-specific information and engineering included in the estimate. For example, a remediation project cost estimate based on a detailed engineering design would represent a higher level of project definition (and lower cost uncertainty) than a cost estimate based on a remedial investigation/feasibility study.

Innovation represents the extent to which the project relies on "tried-and-true" vs. new approaches. Projects with greater technical sophistication in the form of first-of-a-kind technologies are more likely to experience cost overruns. There are two types of first-of-a-kind technologies: those not commercially proven, and those commercially proven technologies integrated in new and unproven ways. **Complexity** measures the number of process steps

[1]Merrow, E. W.. *Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants*, The Rand Corporation, Santa Monica, CA, 1981.

[2]The two drivers are inclusiveness and impurities. Inclusiveness represents the amount of three items included in the scope of a process plant estimate: land purchase/leases/property rentals, initial inventory of parts and materials, and pre-operating plant personnel costs. Impurities represent the level to which impurity buildup, a technical problem in certain types of process plants that results in corrosion of the plant hardware, may exist.

Exhibit 1
Relative Weighting for
Three Cost Uncertainty Drivers

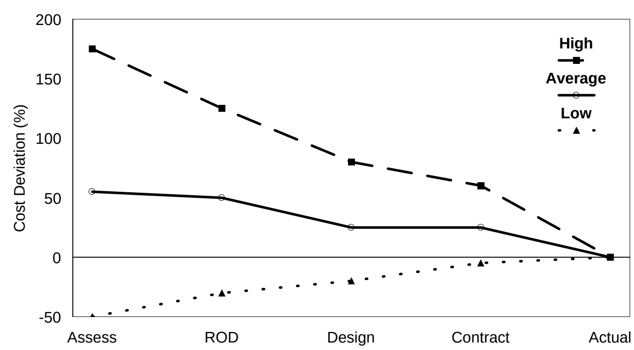


required to execute a project. Past analyses indicate that the more process steps there are in a project, the greater the level of cost uncertainty.

Merrow[1] developed a cost growth model from which a relative weighting system for the three drivers can be developed. Using estimated and actual cost data from 44 process plants, this model allocates cost uncertainties among five cost drivers. Assuming that all cost uncertainty for DOE environmental cleanup projects is attributable to three of those five drivers discussed above—project definition, innovation, and complexity—standard statistical techniques can be employed to develop relative weighting for the three drivers. Exhibit 1 illustrates the results of the analysis attributing relative weights for the three cost uncertainty drivers.

The methodology assigns the above relative weighting to a cost uncertainty range derived from cost data on 40 actual clean-up projects completed over the last decade.[3,4] Exhibit 2 summarizes these data in terms of high, average, and low cost deviations (i.e., the difference between estimated and actual project costs) at different points in time during the project life cycle. Not surprisingly, cost deviations are greatest at the assessment stage of cleanup projects and converge to zero as actual costs are recorded. Although various EM projects are at various stages between the "Assessment" and "Actual" points of the curves in Exhibit 2, the methodology employs the greatest cost uncertainty range, from -50 to +175 percent, as the upper ceiling of cost uncertainty to be conservative and because of an inability to categorize projects. The methodology then adjusts the uncertainty range based on the degree of project definition, innovation, and complexity as described in the following section.

Exhibit 2
Cost Uncertainty Ranges
Over Cleanup Project Life Cycles



EM conducted this analysis at the Project Baseline Summary (PBS) ("project") level. Each of the PBSs represent a distinct group of actions necessary for cleanup and closure of EM DOE sites. For the purposes of this analysis, EM divided PBSs into two major types, support and mission direct. Support PBSs consist of actions which are not directly remediation activities. These include legal action, record keeping, infrastructure maintenance, and other administrative costs. Mission direct PBSs are those that

[3]Schroeder, B.R., and R.F. Shangraw, Jr.. Parametric Tools for Hazardous Waste Projects; *1990 Transaction of the American Association of Cost Engineers*, American Association of Cost Engineers, Morgantown, WV, 1990.

[4]The two primary sources for this paper, Merrow et al. and Schroeder and Shangraw, are both products of DOE funding. Merrow et al. represents one of the first major cost uncertainty efforts for large projects. Schroeder and Shangraw is a continuation of this research, relating specifically to remediation projects.

primarily involve remediation activities, such as waste removal from contaminated media, waste containment, and waste transport. In this analysis, EM established uncertainty percentages for mission direct PBSs using the methodology described below. EM then scored the support PBSs with an uncertainty representing an average of the uncertainty percentages for all mission direct PBSs at the site.

Establishing PBS Cost Uncertainty Ranges

In order to establish high and low project cost estimates, which ultimately defined the cost uncertainty range for each PBS, EM used data from EM's Operations/Field Offices. The following paragraphs discuss the parameters EM employed to evaluate project definition, innovation, and complexity.

Project Definition. The methodology relied on PBS programmatic work scope risk scores to assess project definition. PBS streams and milestones are assigned a programmatic work scope risk on a five point scale with one representing the lowest level of uncertainty and five the greatest level of uncertainty (see text box). EM assigned PBSs to low, medium, or high project definition uncertainty categories based on their work scope risk score(s). Although the use of three categories and the translation of risk scores to categories is somewhat arbitrary, EM believe it is nevertheless a simple, workable approach that produced reasonable results. EM assigned particular scores to categories based on a previously assigned determination in the guidance. For example, the guidance groups the risk scores with 1 or 2 as minor, 3 as intermediate, and a score of 4 or 5 as serious. Unfortunately, not all PBSs have work scope risk scores. In these cases, EM defaulted to a medium project definition uncertainty category for each PBS instead.

Score	Characteristics
One	❑ Project endpoints determined and supported by Stakeholders and Tribal Nations ❑ Waste/material quantities and characteristics well known ❑ Process operations determined and supported by Stakeholders and Tribal Nations Waste/material disposition locations are identified and EIS ROD is pending.
Five	❑ Project endpoints not determined and supported by Stakeholders and Tribal Nations ❑ Waste/material quantities and characteristics not well known ❑ Process operations not determined and supported by Stakeholders and Tribal Nations Waste/material disposition locations are not identified and EIS ROD is not pending.

EM assigned PBSs with high project definition uncertainty the highest possible uncertainty range for project definition. Since project definition accounts for 50 percent of cost uncertainty and the maximum uncertainty range is -50 to +175 percent, high project definition uncertainty translates to a cost uncertainty range of -25 to +88 percent. EM assigned PBSs with medium project definition uncertainty half of the highest possible uncertainty range for project definition or -13 to + 44 percent. EM assigned PBSs with low project definition uncertainty ten percent of the highest possible uncertainty range for project definition or -3 to +9 percent. In light of the somewhat arbitrary nature of these assignments, EM ran several sensitivity analyses using varying scoring breakouts and found the results to be in the same general range.

Innovation. The proposed methodology for the innovation driver is analogous to that for project definition. The manner by which EM attained a PBS's innovation uncertainty was through analysis of the PBS's technology programmatic risk score. The technology risk score is also a number from one to five with one representing the lowest level of uncertainty and five the highest. Specifically, a score of one means that the technical approach for the PBS is being fully executed, all technologies are operating according to specification, and further investments in science and technology are not required to meet cost and schedule requirements. By contrast, a five means that the technical approach has not been identified, key technologies do not exist, and current investments do not support the resolution of the project's science and technology needs. EM assigned each PBS with a technology programmatic risk score into a low, medium, or high innovation uncertainty category based on its technology risk score. As with project definition, some PBSs do not have a technology risk score. In these cases, EM again defaulted to a medium project definition uncertainty category for each PBS.

As with project definition, EM assigned PBSs with high innovation uncertainty the highest possible uncertainty range for innovation. Since innovation accounts for 28 percent of cost uncertainty and the maximum uncertainty range is -50 to +175 percent, high innovation uncertainty translates to a cost uncertainty range of -14 to +49 percent. EM assigned PBSs with medium innovation uncertainty half of the highest possible uncertainty range for innovation or -7 to + 25 percent. EM assigned PBSs with low innovation uncertainty ten percent of the highest possible uncertainty range for innovation or -1 to +5 percent. Again, in light of the somewhat arbitrary nature of these assignments, EM ran several sensitivity analyses using varying scoring breakouts and found the results to be in the same general range.

Complexity. The final driver, complexity, is a more difficult factor to evaluate because there are no data that directly correspond to the number of process steps in a PBS. Therefore, EM used an indirect approach to attain complexity uncertainty. EM established a ranking system based on the types of waste managed within each PBS. EM assumed that:

- PBSs that address high-level waste or spent nuclear fuel have a high degree of complexity.
- PBSs that address transuranic waste or mixed radioactive waste have a medium degree of complexity.
- All other PBSs have a low degree of complexity.

Using Stream Disposition Database information, EM collected data on the waste streams associated with PBSs. Where multiple waste stream types were related to a single PBS, EM relied on the waste stream associated with the greatest complexity uncertainty category. Where no data were available, EM relied on expert knowledge to infer the associated waste streams.

As with project definition and innovation, EM assigned PBSs with high complexity uncertainty the highest possible uncertainty range for complexity. Since complexity accounts for 22 percent of cost uncertainty and the maximum uncertainty range is -50 to +175 percent, high complexity uncertainty translates to a cost uncertainty range of -11 to +39 percent. EM assigned PBSs with medium complexity uncertainty half of the highest possible uncertainty range for complexity or -

6 to + 19 percent. EM assigned PBSs with low complexity uncertainty ten percent of the highest possible uncertainty range for complexity or -1 to +4 percent.

Operations/Field Office Review and Input. EM sent out all scores to Operations/Field Offices in order that they could review and edit the scores for each site to reflect the uncertainties in each PBS more appropriately. This review was especially important for those PBSs for which EM originally defaulted to a medium uncertainty score due to lack of data.

In addition, the Operations/Field Offices were asked to identify any PBSs that already had contingency built in to the base cost estimate. The Operations/Field Offices identified a number of PBS with varying levels of contingency. For those projects that contained already contingencies to account for all or substantially all of the uncertainties, EM excluded the PBS base cost from the Monte Carlo simulation and added those costs back to the results at the end of the simulation. This approach avoided "double-counting" the uncertainty of a project. For PBSs where some—but less than all or substantially all—uncertainties were accounted for, the Operations/Field Offices adjusted the PBS's uncertainty scores to reflect costs already included for uncertainty.

EM also adjusted the base costs for each PBS by extracting FY97, FY98, and FY99 costs. Since these years have passed, there is no uncertainty surrounding their costs. To include them in the simulation would have incorrectly increased the uncertainty of the PBSs. Therefore, EM extracted these costs from the Monte Carlo simulation and added those costs back to the results at the end of the simulation.

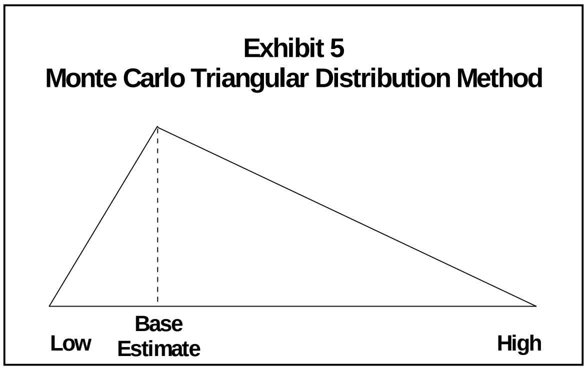
For each PBS, EM then summed the three uncertainty scores to find the total percentage of cost uncertainty. EM then applied this percentage to the base cost, adjusted to exclude FY97, FY98, and FY99 costs as previously explained, in order to find the high and low costs for each PBS.

As previously mentioned, in cases where the PBS did not significantly involve remediation activities and was instead composed of such site support activities as security, grounds keeping, or legal costs, EM scored the PBS with an uncertainty representing an average of the uncertainty percentages for all mission direct PBSs at the Site Summary Level. EM made this assumption to capture the knowledge that the cost uncertainty of an environmental activity should be directly related to the cost uncertainty of support for that activity. In addition, EM scored the PBSs without a clear site link (e.g., EH Health Studies) with an uncertainty equal to the average uncertainty of all mission direct projects.

Establishing Overall Life-cycle Cost Uncertainty Ranges

Following the attainment of high and low costs, Monte Carlo scenarios are run in order to find the cost uncertainty range. Monte Carlo methods, probably the most widely used of all computerized risk analysis methods, rely on the computational power of a computer and a program such as Crystal Ball[5] to randomly select from the possible values that an estimate can assume.

[5]Crystal Ball is a Microsoft® Excel Add-in tool that uses Monte Carlo simulation to help analyze uncertainties given an uncertainty range for each uncertain value (in this case PBS life-cycle cost).



EM entered the base estimate cost, and the high and low costs described above. Due to the fact that the high estimates are a greater percentage above the baseline cost estimates than the low estimates are below the baseline costs, the distribution for each PBS is triangular, as illustrated in Exhibit 5. Given these low, base, and high costs, EM used Crystal Ball to automatically calculate a mean and a standard deviation for each PBS.

Using the Monte Carlo program, many trials can be conducted to simulate reality. Each estimate will randomly fall within the triangular distribution, with the greatest probability of estimates around the base estimate, and the lowest probability around the high and low costs. In other words, over many trials, the selection of the estimates will follow the distribution established (the most likely estimate will be selected most often and the low and high estimates will be selected least often). It is important to note that due to the nature of Monte Carlo analyses and the random seeding it involves, no two runs will yield the exact same data. Therefore, the exact findings of a Monte Carlo analysis can not be precisely replicated. After conducting the trials, EM added back costs for projects that had been previously removed from the analysis as explained above.